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Improved metaheuristic based energy-efficient clustering protocol for wireless sensor networks

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ABSTRACT

Energy-efficient clustering protocols are much sought specially for low-power, multi-functional Wireless Sensor Networks (WSNs). With the application of Computational Intelligence (CI) based approaches, various metaheuristics have been developed for energy-efficient clustering in WSNs. Artificial Bee Colony (ABC) is one such metaheuristic which arose much interest over other population-based metaheuristics for solving optimization problems in WSNs due to its ease of implementation and adaptive nature. However, its solution search equation, which is poor at exploitation process, contributes to its insufficiency. Thus, we present an improved Artificial Bee Colony (iABC) metaheuristic with an improved solution search equation to improve its exploitation capabilities. Additionally, in order to increase the global convergence of the proposed metaheuristic, an improved population sampling technique is introduced through *Student's-t* distribution. The proposed metaheuristic maintains a good balance between exploration and exploitation search abilities with least memory requirements, moreover the use of first of its kind compact *Student's-t* distribution makes it suitable for limited hardware requirements of WSNs. Further, an energy efficient clustering protocol *BeeCluster* based on iABC metaheuristic is introduced, which inherits the capabilities of the proposed metaheuristic to obtain optimal cluster heads (CHs) and improves energy-efficiency in WSNs. Simulation results show that the proposed clustering protocol outperforms other well known protocols on the basis of packet delivery, throughput, energy consumption, network lifetime and latency as performance metric.

1. Introduction

WSNs contain self-configured, distributed and autonomous Sensor Nodes (SNs) that monitor physical or environmental activities like humidity, temperature or sound in a specific area of deployment (Yick et al., 2008). SNs can have more than one sensor to capture data from the physical environment wherever deployed. A sensor with limited storage and computation capabilities receives the sensed data through analogue to digital Converter (ADC) and process it further for transmission to a main location, known as *Base Station* (BS), where the data can be analysed for decision making in variety of applications (Al-Karaki and Kamal, 2004). Every node also acts as a repeater for passing information of other sensor nodes to the sink. The most important part of the sensor node is its power supply, which caters to the energy requirements of sensors, processors and transceiver, however, its limited battery life can lead to premature exhaust of the network due to excessive usage (Akkaya and Younis, 2005). As manual recharging of batteries is not possible in complex deployments, efficient use of the energy becomes a tough challenge in applications where prolonged life of the network is required (Gaura, 2010). A typical WSN scenario is shown in Fig. 1.

Researchers are heavily involved in designing of energy efficient solutions, however, on the other hand network life can also be extended by planning energy efficient approaches. It is well accepted that cluster based hierarchical approach is an efficient way to save energy for distributed WSNs (Abbasi and Younis, 2007; Tyagi and Kumar, 2012), which increase network life by effectively utilizing the node energy, and supports dynamic WSNs environment. In a cluster based WSN, SNs are divided into several groups known as clusters with a group leader known as *Cluster Head* (CH). All the SNs sense data and send it to their corresponding CH, which finally send it to the BS for further processing. Clustering has various significant advantages over classical schemes (Abbasi and Younis, 2007). First, data aggregation is applied on data, received from various SNs within a cluster, to reduce the amount of data to be transmitted to BS thus energy requirements decrease sharply. Secondly, rotation of CHs helps to ensure a balanced energy consumption within the network, which prevent getting specific nodes starved due to lack of energy (Chamam and Pierre, 2010).

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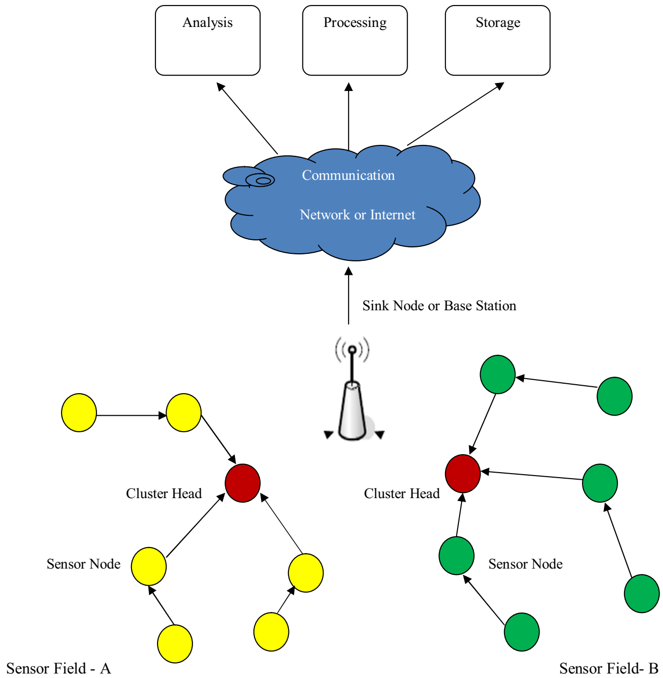

Fig. 1. A typical WSN scenario.

However, the selection of appropriate CH with optimal capabilities while balancing energy-efficiency ratio of the network is a well defined NP-hard optimization problem in WSNs (Khalil and Attea, 2011). Thus, Computational Intelligence (CI) (Kulkarni et al., 2011) based approaches such as Evolutionary algorithms (EAs), Reinforcement learning (RL), Artificial immune systems (AIS), and more recently, Artificial Bee Colony (ABC) have been used extensively as population based metaheuristic for energy-efficient clustering protocols in WSNs (Das et al., 2009). Results prove that the performance of the ABC metaheuristic is competitive to other population-based algorithms with the advantage of employing fewer control parameters, simplicity of use and ease of implementation (Sabat et al., 2010).

However, similar to other population-based algorithms, the standard ABC metaheuristic also faces some challenges, as it is considered to have poor exploitation phase than exploration, moreover convergence rate is typically slower, specially while handling multi-modal optimization problems (Karaboga and Akay, 2009). Therefore, we propose an improved Artificial Bee Colony (iABC) metaheuristic, with an improved solution search equation, which will be able to search an optimal solution to improve its exploitation capabilities and an improved technique for population sampling through the use of first of its kind compact *Student's-t* distribution to enhance the global convergence of the proposed metaheuristic. Further, to utilize the capabilities of the proposed metaheuristic, an improved Artificial Bee Colony based clustering protocol, *BeeCluster*, is introduced, which selects optimal cluster heads (CHs) with energy-efficient approach in WSNs.

2. Related work

We present the vital contributions of the researchers based on Classical as well as CI based metaheuristic approaches as follows: Low-energy adaptive clustering hierarchy (LEACH) (Heinzelman et al., 2002) is a classical clustering protocol which combines energy-efficient cluster-based routing to application oriented data aggregation and achieves better lifetime for a WSN. LEACH introduces algorithm for adapting clusters and rotating CHs positions to evenly distribute the energy load among all the SNs, thus enables self-organization in WSNs. LEACH remains a paradigm architect for designing clustering protocols for WSNs till date. HEED (Hybrid Energy-Efficient Distributed clustering) (Younis and Fahmy, 2004), is another classical clustering protocol that selects CHs based on hybridization of node residual energy and node proximity to its neighbours or node degree thus achieves uniform CH distribution across the network. HEED approach can be useful to design WSN protocols that require scalability, prolonged network lifetime, fault tolerance, and load balancing but it only provides algorithms for building a two-level hierarchy and no idea is presented for designing protocol to multilevel hierarchies. Power-efficient and adaptive clustering hierarchy (PEACH) (Yi et al., 2007) selects CHs without additional overhead of wireless communication and supports adaptive multi-level clustering for both location-unaware and location-aware WSNs but with high latency and low scalability thus making it suitable only for small networks. T-ANT (Selvakennedy et al., 2007), a swarm-inspired clustering protocol, exploits two swarm principles, namely separation and alignment, through pheromone control to obtain a stable and near uniform distribution for selection of CHs. Energy-Efficient Multi-level Clustering (EEMC) (Jin et al., 2008) achieves less energy consumption and minimum latency in WSNs by forming multi-level clustering with minimum algorithm overhead. However, it ignores the issue of channel collision which happens frequently in wireless networks. Energy efficient heterogeneous clustered scheme (EEHC) (Kumar et al., 2009) selects CHs based on weighted election probabilities of each node which is a function of the residual energy and further support node heterogeneity in WSNs. Multi-path Routing Protocol (MRP) (Yang et al., 2009) is based on dynamic clustering with Ant colony optimization (ACO) metaheuristic. A CH is selected based on residual energy of nodes and an improved ACO algorithm is applied to search multiple paths that exist between the CH and BS. MRP prolonged the network lifetime and reduces the average energy consumption effectively using proposed metaheuristic. Energy Efficient Cluster Formation protocol (EECF) (Chamam and Pierre, 2010) presents a distributed clustering algorithm where CHs are selected based on a three-way message exchange between each sensor and its neighbours while possessing maximum residual energy and degree. However the protocol does not support multi-level clustering and considers small transmission ranges. Mobility-based clustering (MBC) protocol (Deng et al., 2011) supports node mobility, hence CHs will be selected based on nodes residual energy and mobility, whereas a non-CH node maintains link stability with its CH during set-up phase. UCFIA (Mao and Zhao, 2011) is a novel energy efficient unequal clustering algorithm for large scale WSNs, which uses fuzzy logic to determine node's chance to become CH based on local information such as residual energy, distance to BS and local density of nodes. In addition, an adaptive max–min ACO metaheuristic is used to construct energy-aware inter-cluster routing between CHs and BS, thus balances the energy consumption of CHs. Distributed Energy-Efficient Clustering with Improved Coverage (DEECIC) (Liu et al., 2012) selects minimum number of CHs to cover the whole network based on nodes local information and periodically updates CHs according to nodes residual energy and distribution. By reducing overheads of time synchronization and geographic location information, it prolongs network lifetime and improves network coverage. Energy-Aware Evolutionary Routing Protocol (ERP) (Attea and Khalil, 2012) is based on Evolutionary algorithms (EAs) and ensures better trade-off between lifetime and node stability period of a network with efficient energy utilization in complex WSNs environment. Harmony search algorithm based clustering protocol (HSACP) (Hoang et al., 2014) is a centralized clustering protocols based on Harmony search algorithm (HSA), a music-inspired metaheuristic, which is designed and implemented in real time for WSNs. It is designed to minimize the intra-cluster distances between the cluster members and their CHs thus optimize the energy distribution for WSNs. BeeSensor (Saleem and Farooq, 2012) is an energy-aware, event driven, reactive and on-demand routing protocol for WSNs. Inspired from biological system of bees